Conference Paper

Elastomagnetoresistive Properties of Films of 3d-Metalls Alloys

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Abstract

Magnetoresistive properties of 3d-metals alloys magnetostrictive films under application of elastic deformations were investigated. Linear stress was shown to have a significant effect on magnetoresistive effect in the films through the rotation of the easy magnetization axis. Dependencies of the relative change of resistivity were obtained in a cyclic deformation regime for films of different compositions.

Keywords: elastomagnetoresistance, exchange bias, films

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1. Introduction

Thin films found application in numerous sensors due to the wide variety of observed properties and phenomena. One of the promising effects is elastomagnetoresistance, which can be utilized in force or pressure sensors. This effect is observed in magnetic materials demonstrating both anisotropic magnetoresistive effect (AMR) [1-5] and magnetostriction [5-9]. In such materials magnetic anisotropy is changing in respond to the magnetoelastic interaction and can be detected as a change of electric resistivity due to the AMR effect.

Films of $Fe_{10}Ni_{90}$ and $Co_{20}Ni_{80}$ alloys are simple examples of elastomagnetoresistive materials having high AMR effect (up to 5-6 % [10]) and magnetostriction of about 20 ppm [11]. However, polycrystalline films of these materials have relatively low induced magnetic anisotropy [4], which is the reason for high magnetic hysteresis. This issue can be solved by introduction of an additional exchange coupled antiferromagnetic [12] of ferromagnetic [13] layer – the source of unidirectional magnetic anisotropy. The presence of the strong exchange coupling was demonstrated to effect strongly both magnetic anisotropy and hysteresis properties of the ferromagnetic layer [13]. In this work, elastomagnetoresistive properties of $Fe_{10}Ni_{90}$ and $Co_{20}Ni_{80}$ free layers as well as FeMn/$Fe_{10}Ni_{90}$ and FeMn/$Co_{20}Ni_{80}$ with unidirectional anisotropy were investigated.

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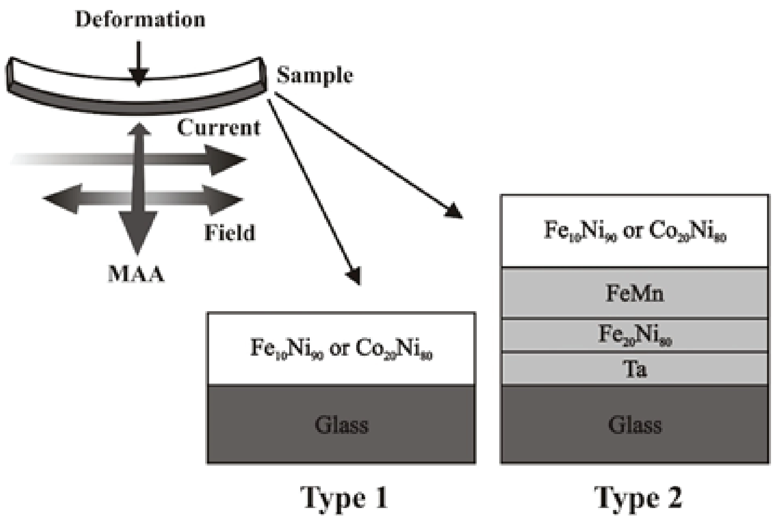

Figure 1: Schematic representation of samples layered structure and the experiment geometry.

2. Methods

Samples were synthesized by magnetron sputtering of target materials onto the Corning glass substrates (thickness of 0.2 mm). DC magnetic field was applied in the direction parallel to the substrate during the deposition in order to induce the easy magnetization axis (EA). Two types of samples were synthesized (presented schematically in Fig. 1). Type 1 samples are single-layer $Fe_{10}Ni_{90}$(80) and $Co_{20}Ni_{80}$(80) films (thicknesses in nm are given in parenthesis). Type 2 samples are films consisting of several layers X/$Fe_{10}Ni_{90}$(80) and X/$Co_{20}Ni_{80}$(80), where X is a group of auxiliary layers Ta(5)/$Fe_{20}Ni_{80}$(5)/FeMn(20) responsible for unidirectional anisotropy in $Fe_{10}Ni_{90}$ and $Co_{20}Ni_{80}$ layers.

Elastomagnetoresistive properties were investigated on 2x15 mm^2 stripes cut perpendicular to the EA. Magnetic properties were measured by means of high-resolution wide-field Kerr microscope. Tensile stress was applied by the controlled bending of the stripes using micrometric translator (Fig. 1). Bending deflection (up to 120 μm) was measured by digital micrometer and converted to the linear tensile stress $\delta = \Delta l/l$. Electric resistance was measured using standard four-probe method in the magnetic field up to 160 Oe.

3. Results

Magnetooptical hysteresis loops obtained on type 1 and type 2 samples in the unstrained state and after application of the tensile stress are presented in Fig. 2. Measurements were performed in the magnetic field oriented along (curves 1) and perpendicular (curves 2) to the EA. Character of curves 1 and 2 implies the presence of the uniaxial magnetic anisotropy for all samples. Besides, type 2 samples demonstrate unidirectional anisotropy (Fig. 2b,d, curves 1) oriented in the direction parallel to the EA. The presence of the unidirectional anisotropy led to the significantly reduced hysteresis

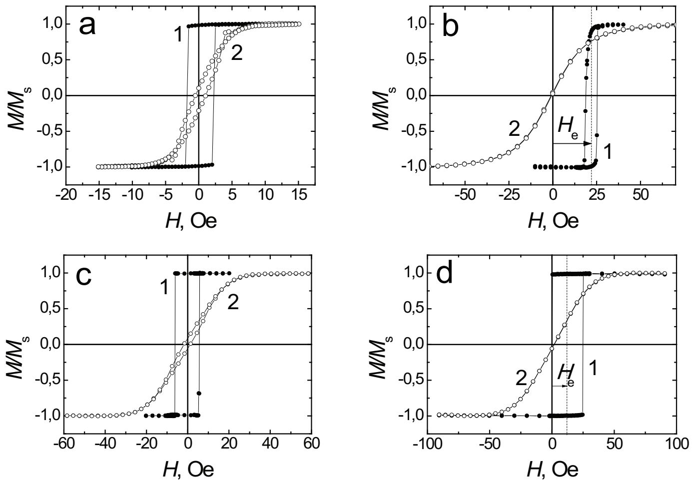

Figure 2: Magneto-optical hysteresis loops measured for $Fe_{10}Ni_{90}$ (a), X/$Fe_{10}Ni_{90}$ (b), $Co_{20}Ni_{80}$ (c) and X/$Co_{20}Ni_{80}$ (d) samples measured with the external magnetic field applied along (curves 1) and perpendicular (curves 2) to the EA.

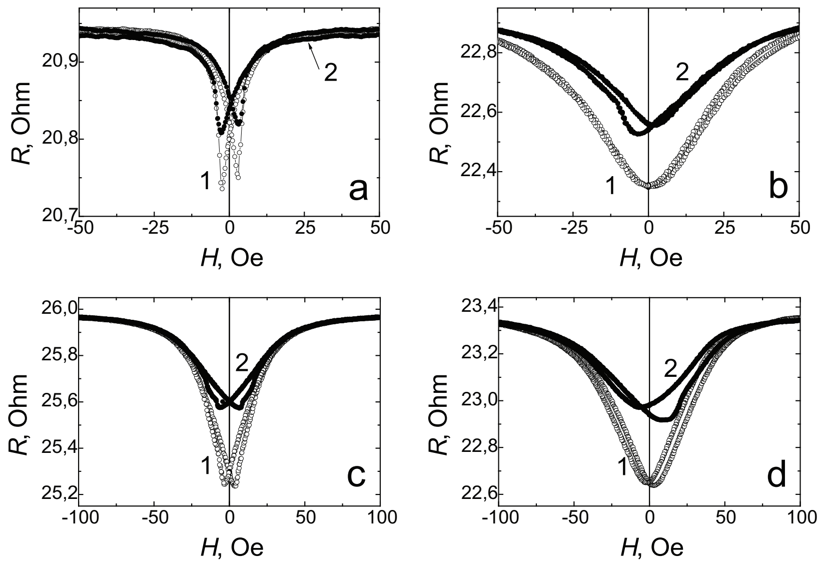

Figure 3: Magnetoresistive loops measured perpendicular to the EA on $Fe_{10}Ni_{90}$ (a), X/$Fe_{10}Ni_{90}$ (b), $Co_{20}Ni_{80}$ (c), X/$Co_{20}Ni_{80}$ (d) samples in the unstrained state (curves 1) and after application of the tensile stress of δ= 0.056 % (curves 2).

and enhancement of the magnetic anisotropy field compared to the free ferromagnetic layers.

The described features of magnetization reversal observed for unstrained samples can also be seen on magnetoresistive hysteresis loops $R(H)$ (Fig. 3, curves 1), measured according to the scheme presented in Fig. 1. As one can see, $R(H)$ loops corresponding to the type 2 samples (Fig. 3b,d) show the same magnetic anisotropy enhancement as in the single-layer films.

Application of the tensile stress leads to the substantial transformations of magnetoresistive loops of both types of samples (Fig. 3, curves 2, 3). As can be seen, the amplitude and the slope changes strongly for magnetoresistive loops measured with

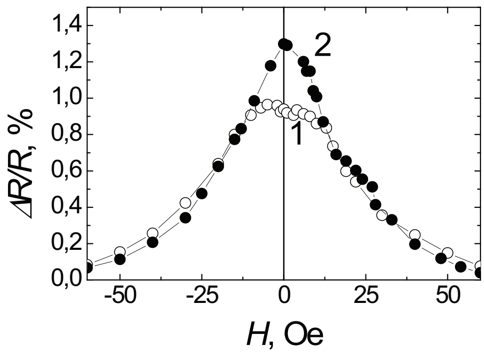

Figure 4: Dependencies of the relative change of electric resistivity $\Delta R/R$ on the applied magnetic field H measured for δ=0.05% on X/$Fe_{10}Ni_{90}$ (curve 1) and X/$Co_{20}Ni_{80}$ (curve 2) samples.

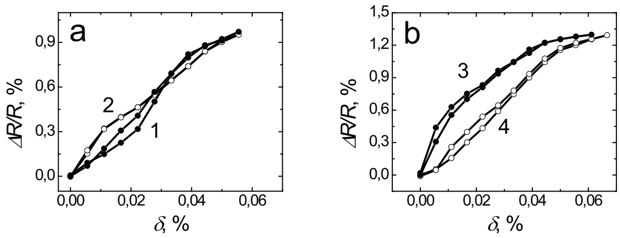

Figure 5: Dependencies $\Delta R/R(\delta)$ measured for (a) $Fe_{10}Ni_{90}$ (curve 1) and X/$Fe_{10}Ni_{90}$ (curve 2) samples; (b) $Co_{20}Ni_{80}$ (curve 3) and X/$Co_{20}Ni_{80}$ (curve 4) samples in the external magnetic field H_{max}.

the external magnetic field applied perpendicular to the EA. These changes take place due to the negative constant of magnetostriction, which is typical for the considered compounds [6]. Magnetoelastic coupling contributes to the enhancement of the magnetic anisotropy of the film, which leads to the observed changes in magnetoresistive loops.

Comparing curves 1 and 2 in Fig. 3, one can see that the sensitivity of magnetoresistive effect depends on the value of the applied external magnetic field. To demonstrate this effect, $\Delta R/R(H)$ dependencies measured on the deformed (tensile stress δ = 0.05 %) samples with unidirectional anisotropy are shown in Fig. 4. The obtained curves are nonmonotonic and show maximum value around zero magnetic field for X/$Fe_{10}Ni_{90}$ and X/$Co_{20}Ni_{80}$ samples. It should be noted, that although the maximum effect measured on X/$Fe_{10}Ni_{90}$ film (curve 1) is lower than that of the X/$Co_{20}Ni_{80}$ film (curve 2), it has better stability in the wide magnetic field range.

Dependencies of the relative change of resistivity on the value of the applied linear tensile stress $\Delta R/R(\delta)$ measured on type 1 (a) and type 2 (b) samples are presented in Fig. 5. Here, we choose the external magnetic field H_{max} corresponding to the maximal $\Delta R/R$ value (Fig. 4). Measurements were performed in the cyclic deformation regime, which allowed us to estimate hysteresis of the functional dependencies. The deformation range was limited by the maximum value of breaking stress of the glass ($\delta \leq$ 0.065 %). Dependencies $\Delta R/R(\delta)$ measured for X/FeMn film (Fig. 5a, curve 2) demonstrate almost zero hysteresis, comparing to the single-layer $Fe_{10}Ni_{90}$ film.

For $Co_{20}Ni_{80}$-based films (Fig. 5b), hysteresis of $\Delta R/R(\delta)$ dependencies is clearly visible for both curves 3 and 4, which is a consequence of the overall higher magnetic hysteresis comparing to $Fe_{10}Ni_{90}$ films. For all considered samples, strong nonlinearity of $\Delta R/R(\delta)$ dependencies is observed, which is to be expected taking into account the mechanism behind the effect.

4. Conclusion

The investigation of elastomagnetoresistive properties of 3d-metal alloys films demonstrated high magnetoresistive response to the application of the elastic tensile stress as well as the possibility to reduce the magnetic hysteresis by implication of the unidirectional anisotropy. Functional properties of the sensitive medium can be further improved by optimization of the experimental geometry, value of the magnetic field, and involvement of the controlled annealing. The obtained results show that the elastomagnetoresistive can be successfully implied in force or pressure sensors.

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